UNIVERSITI PUTRA MALAYSIA

Flow analysis of water with aluminum oxide nanoparticles in a 90° bend pipe with injection using computational fluid dynamics

Hadi Mahdizadeh

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FLOW ANALYSIS OF WATER WITH ALUMINUM OXIDE NANOPARTICLES IN A 90° BEND PIPE WITH INJECTION USING COMPUTATIONAL FLUID DYNAMICS

By

HADI MAHDIZADEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to my parents for their endless love, support and encouragement.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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August 2018

Chairman : Professor Nor Mariah bt. Adam, PhD, PE
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In several heat exchangers, the shape of the pipes is bent. Flow behavior in a curved tube is much more complex than straight pipes. Also, Nano-fluids are utilized in many industrial applications for increase thermal efficiency. Therefore, the aim of this study is investigation of the effect of injection into a 90° bend tube with $A1_2O_3$ Nano-fluid. Computational fluid dynamics study of a flow through a bent tube of 90° via fluid injection was performed using ANSYS FLUENT software. Conservation equations of mass, momentum and energy are discretized using finite volume method. SIMPLE algorithms have been used to solve it. The effects of volume fraction of Nano-fluid, (0%, 2%, 4%, 6%) fluid injections number (0, 1, 2) and position of injection before and after bend have been investigated. Evaluation of best performance of mixing injection and bend in different positions and analyzing the effect of Nano-fluid volume fraction on injection is done for having most Nusselt number and lowest pressure drop in pipe. The results show that the using nanoparticles in bent tube increase the heat transfer performance by 8%. The results obtained show that increasing the volume fraction has a direct impact on decreasing the heat transfer. Even with increase of volume fraction from 2% to 6%, the Nusselt number decreased by 0.7%. By investigation of distance of two injections, the maximum heat transfer has obtained in the injection with distance of 2.5 times of pipe diameter. For study of position of injections and number of it, the geometry with one injection before the bend has the best heat transfer rate and the lowest pressure

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS ALIRAN AIR BERCAMPUR BAHAN NANO ALUMINUM OKSIDA DALAM PAIP BENGKOK 90^{o} DENGAN SUNTIKAN AIR MENGGUNAKAN KAEDAH PENGKOMPUTERAN DINAMIK BENDALIR

Oleh

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Dalam kebanyakan penukar haba, bentuk paip adalah bengkok. Kelakuan aliran di didalam paip yang bengkok adalah lebih kompleks daripada paip yang lurus. Juga bendalir nano banyak digunakan dalam penggunaan industri supaya dapat meningkatkan kecekapan termal. Olehi tu, tujuan kajian ini adalah mengkaji kesan suntikan air ke dalam tiub bengkok 90^{o} berisi air dan bendalir nano $A1_2O_3$. Kajian aliran tiub bengkok 90^{o} dengan suntikan air menggunakan kaedah pengkomputeran dinamik bendalir perisian ANSYS FLUENT.Persamaan-persamaan pengabadian jisim, momemtum dan tenaga telah terdiskret menggunakan kaedah isipadu finite (Finite Volume Method). Algorithma SIMPLE telah digunakan sebagai kaedah penyelesaian.

Kesan pecahan isipadu bendalir nano, (0%, 2%, 4%, 6%) untuk suntikan bendalir nombor (0, 1, 2) dengan kedudukan suntikan sebelum dan selepas paip bengkok telah disemak. Penilaian prestasi suntikan campuran ke bahagian bengkok pada beberapa kedudukan serta analisis kesan pecahan isispadu dijalankan untuk keadaan nilai angka Nusselt tertinggi dan kesusutan tekanan terendah dalam paip. Keputusan meningkatkan dengan penggunaan bendalir nano peningkatan prestasi kadar haba pindah sebanyak 8%. Keputusan diperolehi juga menunjukkan pertambahan pecahan isipadu mempunyai kesan langsung menurunkan pemindahan haba. Dengan penambahan pecahan isipadu dari 2% kepada 6%, nilai angka Nusselt berkurang sebanyak 0.7%. Dengan mengkaji jarak antara dua suntikan, nilai pemindahan haba maksimum diperolehi pada jarak suntikan 2.5 kali ganda diameter paip. Untuk kajian kedudukan suntikan dan bilangan, geometri dengan satu suntikan sebelum paip membengkokm endapatkan kadar pemindahan haba terbaik dengan nilai tekanan terendah.

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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LIST OF SYMBOLS

a	Aggregate
θ	Angle
AL_2O_3	Aluminum Oxide
b	Base fluid
CFD	Computational fluid dynamics
CuO	Copper Oxide
d	Diameter of injection (mm)
D	Diameter of pipe (mm)
eff	Effective
μeff	Effective dynamic viscosity
f	Fluid
i	Inner
L	Length
m	Mean
nf	Nanofluid
Nu	Nusselt number
o	Outer
dp	Particles diameter (nm)
P	Pressure
Re	Reynolds number
SiO_2	Silicic Oxide
ρf	The mass densities of the based fluid
ρnf	The mass densities of solid nanoparticles
k	Thermal conductivity (W/m k)
V	Velocity (m/s)
w	Wall
Nu	Nusselt number

Greek Symbols

δt	Thermal boundary layer thickness [m]
μ	Viscosity [Pa s]
τ	Shear stress [s^{-1}]
φ	Particle volume fraction [-]
ρ	Density [kg m-3]

CHAPTER 1

INTRODUCTION

1.1 Background

Thermal energy is an engineering practice that is concerned with the rate of heat transfer whether transferring the heat into or out from the system (Cengel 2008). A deeper understanding on heat transfer mechanisms is required to design a practical invention involving heat transfer. For example, increase the heat flow of microprocessors by using nano fluids can reduce the size with more heat transfer rate. Thus, the current and envisioned application in such miniaturized devices call for nano fluids to remove heat as efficiently as possible (Shanthi et al 2012). For nuclear power industry, by increasing the forced convective of electricity of chiller system in a nuclear system Eastman, (Choi, Li, Thompson, & Lee 1997). These advanced systems require higher heat fluxes with improved energy efficiency and enhanced heat dissipation. Thus, improvement for heat transfer efficiency of conservative fluid is obligatory to satisfy the necessities of thermal management.

Liquid or gas flow through pipes or ducts is commonly used in heating and cooling applications and fluid distribution networks. The fluid in such applications is usually forced to flow by a fan or pump through a flow section and also pay attention to friction, which is directly related to the pressure drop and head loss during flow through pipes and ducts. The pressure drop is then used to determine the pumping power requirement. A typical piping system involves pipes of different diameters connected to each other by various fittings or elbows to route the fluid, valves to control the flow rate, and pumps to pressurize the fluid (Taylor, Das, Choi, & Patel 2007)

Fluid flow in a curved duct is one of the main and most important flows in fluid mechanics. It should be indicated that most of research so far is limited to newtonian fluids Abbasi & Pid (2013) stated with few considering non-newtonian fluids, the flow of non-newtonian fluids particularly viscoelastic fluids in curved ducts, also has important practical applications, such as the supply of fluids via pipe lines in the oil and petrochemical industries, food production, the fabrication of chemical materials, medical applications, and the injection of polymeric materials (Norouzi, Kayhani, Shu, & Nobari 2010).

Khaled & Vafai (2005) focused the study by reducing the particle size to nano size of nano fluids and proved its effectiveness in achieving heat transfer enhancements. Chopkar et al (2008) observed that when the nanoparticle was dispersed in water and ethylene glycol, the thermal conductivity of nanofluid is higher than the based fluid. The solid particles in ultra-fine size were able to suspend uniformly in the base fluids thus, improving the thermal conductivity of the liquid. The review of Azmi et al (2016) and Godson et al. (2010), the thermos-physical properties such as thermal conductivity and dynamic viscosity of nanofluids is enhanced compared to traditional heat exchanger. Today, it can be seen some changes in heat exchangers likes changing the shape of tube Niazmand (2010) and adding bends for achieving more efficiency.

A few studies have reported Akbari, M and Aly, (2009) the convective heat transfer of different nanoparticles disparities dispersed in conventional fluids such as oil, water using Computational fluids dynamics (CFD). CFD is a method to investigate the fluids flow of the system by using numerical and algorithm analysis, which is a standard implement to design and analyze the engineering problems involving Multi physics phenomena. Many commercial CFD software like FLUENT, ANSYS CFX, COMSOL and Open FOAM are able to model flow. Every of these commercial codes have a different method and algorithms for CFD simulation. Also, many researchers have developed codes in FORTRAN or MATLAB for a special simulation case. With the numerical results, the researcher is able to preview the solution of the problem, while improving the system before the experimental stage. For example, Khanafer & Vafai(2011)studied heat transfer performance of copper oxide (CuO) dispersed in flow in flat tubes. The results show that the heat transfer coefficient has increased about 14% at 2% volume concentration compared to base fluids. Wang & Mujumdar(2008)also analyzed the heat transfer performance of aluminum oxide (Al_2O_3), copper oxide (CuO) and titanium oxide (TiO_2) dispersed in water flow in horizontal ducts. A positive trend was observed in heat transfer coefficient when the volume concentration and Reynolds number increased.

Vajjha, Das, & Namburu(2010) determined the heat transfer coefficient and wall shear stress increased when the flattening increased at aluminum oxide (Al_2O_3) nanoparticles dispersed in water in mixture phase with laminar flow. A similar result from Zhao et al (2016) showed that the heat transfer coefficient and pressure loss have a significant enhancement when the tube flattening is decreased, when aluminum oxide (Al_2O_3) nanoparticles are dispersed in water with laminar flow.

1.2 Problem statement

Many appliances need to have the high heat transfer performance to guarantee the quality and also to increase the efficiency of equipment. The design of curved pipes, for increasing the heat transfer in many applications in various industries such as air conditioners, micro-electrical, heat exchangers, cooling Ayad Jasim Jaber Al-Talqani, (2014).

In many heat exchangers, the shape of the geometry designed is also bent to reduce overall However, bending can increase the heat transfer rate, as shown in Table 1.1, where bending causes a higher pressure drop. Considering that the goal is to produce more heat transfer at the lowest cost, the use of injection is considered to increase the heat transfer rate of the heat exchanger. On the other hand, the lowest pressure drop in the various combinations of injection and bending is also considered, because the higher the pressure drop, the larger the pump is required to pump the flow.

Table 1.1 : Total pressure drop for different nanoparticle concentrations in both geometries (J. Lee & Mudawar 2007)

φ (volume %)	∆P [Pa] (curved pipe)	∆P [Pa] (straight pipe)
0	157	113
2	477	348
4	1847	1379
6	10016	7686

One the application of bent pipes is in the heat exchangers as shown in Figure 1.1. The curved pipes flow behavior is more complex than straight lines. Because with bend, the flow has some gradient in velocity and pressure. Sometimes because of not proper design of bend radius, the flow energy loss in the bend might be high values. Knowing about the flow behavior in this equipment is mandatory for designer to have the best performance.

Figure 1.1 : Using Bend tubes in the heat exchangers (Vasu et al. 2012)

The simulation of fluid and heat transfer inside the tubes, usually is to obtain pressure drop, heat transfer coefficient and the friction coefficient of the wall pipe.

Although many investigators Dutta and Nendi (2015), Akbari et al. (2008) and Carlssun (2014) have studied the problem, the results which they have obtained have not been satisfactorily correlated. The pressure losses in such bend pipes considerable engineering importance. The pressure drops suffered in a bend are caused by both friction and momentum exchanges resulting from a change in the direction of flow. The main characteristics of fluid flow through pipe bends are the presence of adverse pressure gradient developed by the centrifugal force acting on the flow. Due to the presence of centrifugal force and pressure gradient, the fluid moves towards the outer side of the bend and comes back towards the inner side this increase of pressure loss experienced in the pipe bends are generated by friction and momentum exchanges appearing from the change of flow direction. Reynolds number, bend curvature ratio and bend angle are the depending factors for this (Dutta & Nandi, 2015). Therefore, investigations of the flow through bends are of great significance in understanding and improving their performance and minimizing the losses. For a tough bend curvature, this adverse pressure gradient near the inner wall may start the flow separation developing a secondary flow allowing a large increase in pressure loss (Carlssun 2014).

There is an application in bending pipes, where, there is problem of pressure drop in heat transfer in bend, therefore, there is a need to inject to several areas in bend of pipe. It can be executed with using an impinging jet with Nano fluid before and after bend. Also, an impinging jet to increase heat transfer ratio of fluid flow. Curved pipes give better efficiency of resources nevertheless, the pressure loss due to bends as well as sediment and falling pose a performance issue. The other issue is about the requirements for higher heat transfer rates as parts of tubes getting smaller and need lower space and volume for installation (Tamilarasan, & Sendhilnathan 2015).

There is potential to the usage of nano fluid injection for curved pipe enhances heat transfer and simultaneously reduces pressure loss. Nano fluids is used in electrical and spacing industrial design, that allows the heat exchanger with smaller dimension, light weight, high efficiency and can remove the pressure drop and sediment in bend. It was observed that it increases heat transfer coefficient in the curved pipes from mixture curved pipe. The increase in heat transfer rates due to the curvature effects and Nano fluids are accompanied by an undesirable effect which is an increase in pressure drop. In Table1.1, the total pressure drops across the pipe for both geometries at different nanoparticle concentrations are listed. As expected, the pressure drops in a curved pipe are higher than those in a straight pipe (Dutta & Nandi 2015). However, the pressure drop is very strongly influenced by the nanoparticle concentration such that, for a 6% concentration, the pressure drops increase by almost two orders of magnitude in both geometries. Table 1.1 also shows that the pressure drop due to curvature effects is relatively small as compared to nanoparticle effects (Lee et al. 2007).

Injection of water decreases the thickness of boundary layer, Mukesh Kumar, Palanisamy, Kumar, Tamilarasan, & Sendhilnathan (2015) therefore significant improvement in the rate of mass and heat transfer and also momentum is achieved. Using jets encounter is one of the new methods regarding this issue. The resistance against the transmission is decreased by applying injection momentum to the exiting fluid from the nozzle. The fluid hits the wall and it is disturbance the process of the layer boundary. Furthermore, heat transfer rate is increased due to turbulent flow caused by injection. Although, the position and number of injection need to investigation at this project. The effect of injection with bend is a question at this study. Nanoparticle diameter is 100 nm. Aluminum oxide nanoparticles are used due to good thermal conductivity and low price compared to copper and gold nanoparticles, and its low cost is the main reason for using aluminum oxide.

1.3 Aim and Objective

The overall objective is about investigate the effect of injection of water into a 90° bend before and after bend. Specific objectives are as following:

1. To analyze effect of injection on heat transfer of bend tube and pressure drop.
2. To evaluate best performance of mixing injection and bend in different positions
3. To analyze effect of Nano fluid volume fraction on injection.

1.4 Scope of the study

1- Reynolds number is ranging from 30000 to 60000. This range obtain from changing volume fraction (2% to 6%) (Akbari 2008).
2- Assuming the type of flow is fully turbulent and fixed heat transfer convection in the curved tube with circular cross sections.
3- Incompressible flow, three-dimensional flow, Single phase flow, which is not assumed at this study interaction of nanoparticles and fluid, for Nano fluid simulation (Ito 1987).
4- Steady state flow.
5- Nano fluid consists of Al_2O_3 with volume fraction (0, 2, 4 and 6%) suspended in water as a base fluid. The selection of this volume fractions is based on other researches in the chapter 2. The reason of using this nono particle is for being cheap in industry and performance is proper. The diameter of nano particle is 100 nanometers. For more than 6 percent volume fraction, the fluid is high viscous and it is not useable (Shamshirband et al 2015).
6- Using CFD commercial software ANSYS FLUENT to model the internal flow in the curved tube.
7- Δp range is between 50000 to 100000 depending on injections.
8- limited to 2 injections of water before and after bend

1.5 Limitation:

The first limitation, is interaction of solid particles and fluid that it is not possible to model at this research study because need knowledge in the field of fluid solid interaction (FSI). In this study is assumed the mixed flow is homogenous and have just thermal properties of nanofluid. Other limitations imposed to the module processing, restrict the possibility to enlarge the pipe geometry, analyzing bends in series or even further injections to the pipes. This study investigates four injections where two are before the bend and the other two are after the bend.

1.6 Thesis layout

Chapter 1 contains introductory information as well as the problem statement and scope of this study. Applications of the study and the objectives of the project are also reported. And also, Nano fluid definition and types and their applications are described.

Chapter 2 presents the literature review which is related to the fluid flow and heat transfer problem in curved channels with various geometries involving experimental and numerical studies with different types of working fluids. The first section presents the fluid flow and heat transfer through curve channels, while the last section is related to nanoparticles and Nano fluids parameters, application, production and thermophysical properties.

Chapter 3 focuses on the mathematical and theoretical aspects governing the forced turbulent convection heat transfer for three-dimensions in a curve channel. This chapter shows the numerical procedures for solving the present problem in details as well as the assumptions and limitations of boundary conditions for the computational domain are also mentioned. Furthermore, the analysis and equations of Nano fluids thermophysical properties are presented according to their diameter and volume fraction.

Chapter 4 parameters results and discussions about modeling and researches related to problem solving and then after ensuring of the accuracy of the solution will check the geometry. First will discuss about the two-dimensional curved tube with no injection. After that velocity and turbulence intensity are due to bends checked and validated with experimental data is sent. Then there is the infusion of two-dimensional tube bending has been studied and described the flow physics. The following are three-dimensional simulation results are described. The effect of different concentrations of Nano-fluid investigated and also the effect of Reynolds.

Chapter 5 provide parameters about the overall conclusion will be discussed and also recommendations for further work will be discussed.

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